Masses and Luminosities of X-Ray Binaries

Principal Investigator: Andreas Quirrenbach (UC San Diego)

Team Members:
Sabine Frink (UC San Diego), John Tomsick (UC San Diego)

Summary

Using SIM, we will perform narrow-angle observations of several X-ray binaries to determine their orbits, and we will observe about 50 X-ray binary systems in wide-angle mode to measure their distances and proper motions. Sources with mass estimates for the compact component of greater than $3\,M_\odot$ are generally called "black hole candidates" since this mass is above the theoretical neutron star limit. Narrow-angle observations of these sources provide a direct test of the dynamical mass estimates on which the black hole evidence is based. Better measurements of the black hole masses will provide constraints on possible evolutionary paths that lead to black hole formation. When combined with X-ray data, mass measurements may provide additional constraints on the black hole spin. Precise mass determinations of neutron star systems can address the question of whether neutron stars can be significantly more massive than $1.4\,M_\odot$, which would eliminate soft models of the neutron star equations of state. The wide-angle observations will probe the Galactic distribution of X-ray binaries through parallaxes and proper motions. They will also eliminate the uncertainties in the luminosities of individual sources, which is currently up to a full order of magnitude. This will enable more detailed comparisons of X-ray observations to physical models such as advection-dominated accretion flows (ADAFs). We intend to carry out the following measurements:

- Determine the orbits of two black hole candidates to measure the black hole masses.
- Obtain precise mass measurements for two neutron star systems to constrain neutron star equations of state.
- Determine the distances and thus luminosities of selected representatives of various classes of X-ray binaries (black hole candidates, neutron stars, jet sources).
- In the process of distance determination, proper motions will also be measured, from which the age of the population can be estimated.

Mass Measurements: Current Status and Methods

The following equation shows the parameters that must be determined to measure the compact object mass (M_X) for X-ray binaries using the current methods

$$M_X = \left(\frac{1+q}{q}\right)^2 \frac{f_{\rm opt}}{\sin^3 i} \quad , \qquad (3)$$

where $f_{\rm opt} = PK_{\rm opt}^3/2\pi G$, P is the orbital period, i is the binary inclination, q is the mass ratio of the binary components ($q = M_X/M_{\rm opt}$) and $K_{\rm opt}$ is the semi-amplitude of the radial velocity curve for the optical companion. For black hole and non-pulsating neutron star X-ray binaries, measurements of i and q depend on modeling of the system, introducing significant uncertainty. A direct measurement of q is possible for pulsating neutron star systems, but modeling is still necessary to determine i. Figure 1 shows the neutron star and black hole masses that have been measured.

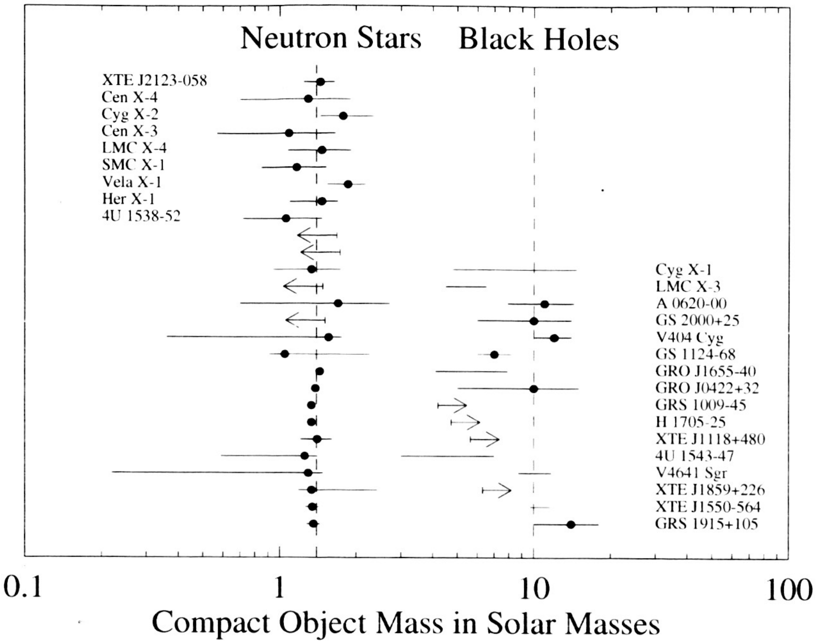

Figure 1: Compact object mass measurements as of 2001 November. There is an apparent gap between the neutron star masses, which cluster near $1.4\,M_{\odot}$, and the higher black hole masses. The neutron star X-ray binary systems are labeled, and the unlabeled systems are binary radio pulsars.

Narrow-Angle SIM Observations

The main goal of the narrow-angle SIM observations is to measure compact object masses in black hole and neutron star X-ray binaries. The size of the astrometric signature depends on the binary orbital period, the masses of the binary components and the distance to the source. Figure 2 shows simulated SIM observations for two black hole systems (Cyg X-1 and GRO J1655–40) with significantly different binary inclinations (i).

Wide-Angle SIM Observations

For the wide-angle SIM observations, the goals are to measure the distances and proper motions for about 50 X-ray binaries. Currently, distances to most X-ray binaries are very uncertain, leading to large uncertainties in the luminosities of these sources. Here, we list some of the source types we plan to observe, and discuss motivations for the SIM observations.

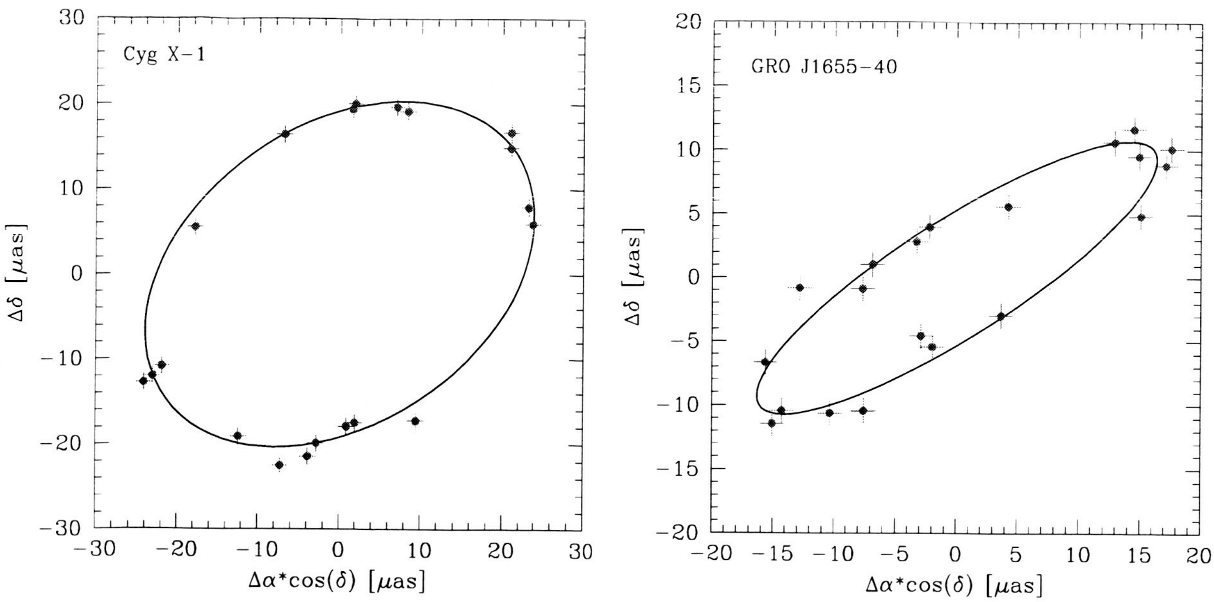

Figure 2: *Left panel*: Simulation of *SIM* observations of Cyg X-1, showing that *SIM* will be able to detect the binary motion of the system. A binary inclination of 47° was assumed. *Right panel*: Simulation of *SIM* observations of GRO J1655–40, assuming a binary inclination of 70°.

- A class of neutron star X-ray binaries called "Z-sources" (e.g., Sco X-1, Cyg X-2, GX 17+2) are thought to emit at close to the Eddington luminosity. Distances are necessary to determine if this is the case.

- Low magnetic field neutron stars produce X-ray bursts (e.g., EXO 0748-676, 4U 1254–690). It is important to know the X-ray burst luminosities for theoretical models of this phenomenon.

- Observations of X-ray transients in quiescence (e.g., GRO J1655–40, Cen X-4, Aql X-1) suggest that black hole systems are less luminous than neutron star systems for a given mass accretion rate. According to the ADAF model, this may demonstrate the presence of black hole event horizons.

- Accurate distances to radio jet sources (e.g., GRO J1655–40, XTE J0421+560, SS 433, V4641 Sgr) are important for determining the jet velocities.

- Some sources at high Galactic latitude appear to be unusually far from the Galactic plane (e.g., Her X-1).

- Proper motion measurements will allow us to estimate the age of the X-ray binary population.